STATUS REPORT

Contract No. Nonr-2964(01), NR 017 208

Robert G. Morris, Principal Investigator
South Dakota School of Mines and Technology
Rapid City, South Dakota

1 October 1964 - 30 September 1965

HIGH-TEMPERATURE THERMAL CONDUCTIVITY MEASUREMENTS IN SEMICONDUCTORS

a) <u>Technical Reports</u>

TR 13 "The Thermal Conductivity and Seebeck Effect of Impure Indium Antimonide in a Magnetic Field," Eldon F. Ault, Master's Thesis, South Dakota School of Mines and Technology, 1964, Issued 1 November, 1964.

<u>Published Articles</u>

None; however, publication is pending on three articles.

b) <u>Names of Graduate Students and Post-Doctoral Personnel Associated with the Project and Their Status</u>

<u>Graduate Students</u>

1. Ralph L. Benbow, about 4/10 time — October 1964 - June 1965
   full time — July - August 1965
   Mr. Benbow's thesis on thermal conductivity of solicon at high temperatures has run into severe experimental difficulties. It will probably be finished by 1 November 1965.

2. Ronald J. Holyer, about 4/10 time — October 1964 - June 1965
   full time — July - August 1965
   Mr. Holyer's thesis on thermal conductivity of silicon at low temperatures will be issued 1 October 1965 as Technical Report 14. Mr. Holyer is now employed at Texas Instruments.

3. Ronald R. Cox, about 4/10 time — September 1965
   Beginning work for Master's degree.

4. Emery J. Stephans, about 4/10 time — September 1965
   Beginning work for Master's degree.

<u>Post-Doctoral Personnel</u>

1. Dr. R. G. Morris, about 2/10 time — October 1964 - June 1965; September 1965
   full time — July - August 1965
   Principal Investigator; Professor of Physics, Head of the Department

2. Dr. R. D. Redin, about 2/10 time — October 1964 - June 1965; September 1965
   full time — July - August 1965
   Co-Investigator; Associate Professor of Physics.

c) Doctorates Earned by Graduate Students

None. M.S. is highest degree offered by College.

d) Other Government-Sponsored Research with which the Principal Investigator is Associated

None.

e) Summary of Work

1. OBJECTIVES: The objectives of the work are to measure the contact and bulk thermal conductivities of semiconductors at temperatures above room temperature by means of the series comparative method. To these has been added the measurement of thermal conductivity at temperatures below room temperature.

2. DOPED N-TYPE INDIUM ANTIMONIDE: Mr. Eldon F. Ault successfully defended his M.S. thesis entitled "The Thermal Conductivity and Seebeck Effect of Impure Indium Antimonide in a Magnetic Field" in October 1964 and the thesis was issued as Technical Report No. 13 on 1 November 1964. A paper based on this work and earlier work of Rodenberg on p-type InSb was presented at the April 1965 meeting of the South Dakota Academy of Science and will be published in the Proceedings. Ault is now at Dow Chemical Co., Midland, Michigan.

Thermal conductivity K and electrical conductivity σ have been measured on samples of the semiconductor indium antimonide (InSb) to which impurities from either the third column (giving p-type InSb) or from the fifth column (giving n-type InSb) of the periodic table had been added. The effect of these impurities on the conductivities was measured over the range 340° - 650°K. σ is generally larger in the impure than in pure samples, while K is smaller for p-type InSb and somewhat larger for n-type InSb than for pure InSb. Calculations show that the lattice part of K decreases in both cases.

3. HIGH-TEMPERATURE MEASUREMENTS: Mr. Ralph Benbow has been measuring n-type silicon ($N_D = 5(10)^{19}$ cm^{-3}) 30-1000°C. Previous measurements here were to 700°C. He has used silicon standards (higher purity) and Armco iron standards. Tungsten-niobium thermocouples were used at the start of the work but now he is using Chromel-Alumel couples. These are attached to niobium wires wedged into holes cut into the samples.

The measurements are plagued with contact difficulties - both between samples and standard and between samples and the thermocouples. Sodium silicate and silicone greases were unstable at the higher temperatures. Two high-temperature adhesives from the Whittaker Corporation, Los Angeles, Imidite 850 and Narmcad, have been used with considerable success between samples and standard. Imidite 850 is superior to Narmcad.

Figure one shows data to 1075°K. Solid lines are experimental curves of Slack and Glassbrenner (Phys. Rev. 134, A1058(1964)) as well as a curve of lattice conductivity calculated here by Benbow on the College IBM 1620 computer.

4. LOW TEMPERATURE THERMAL CONDUCTIVITY: Our liquid nitrogen plant went into operation in January 1965. Mr. Ronald J. Holyer successfully defended his M.S. thesis entitled "A System for Low-Temperature Measurements of Silicon from 77° to 300°K" on 2 September 1965. He is now employed at Texas Instruments in Dallas. The Abstract of the thesis is appended to this report. The thesis will be released as a Technical Report on 1 October 1965.

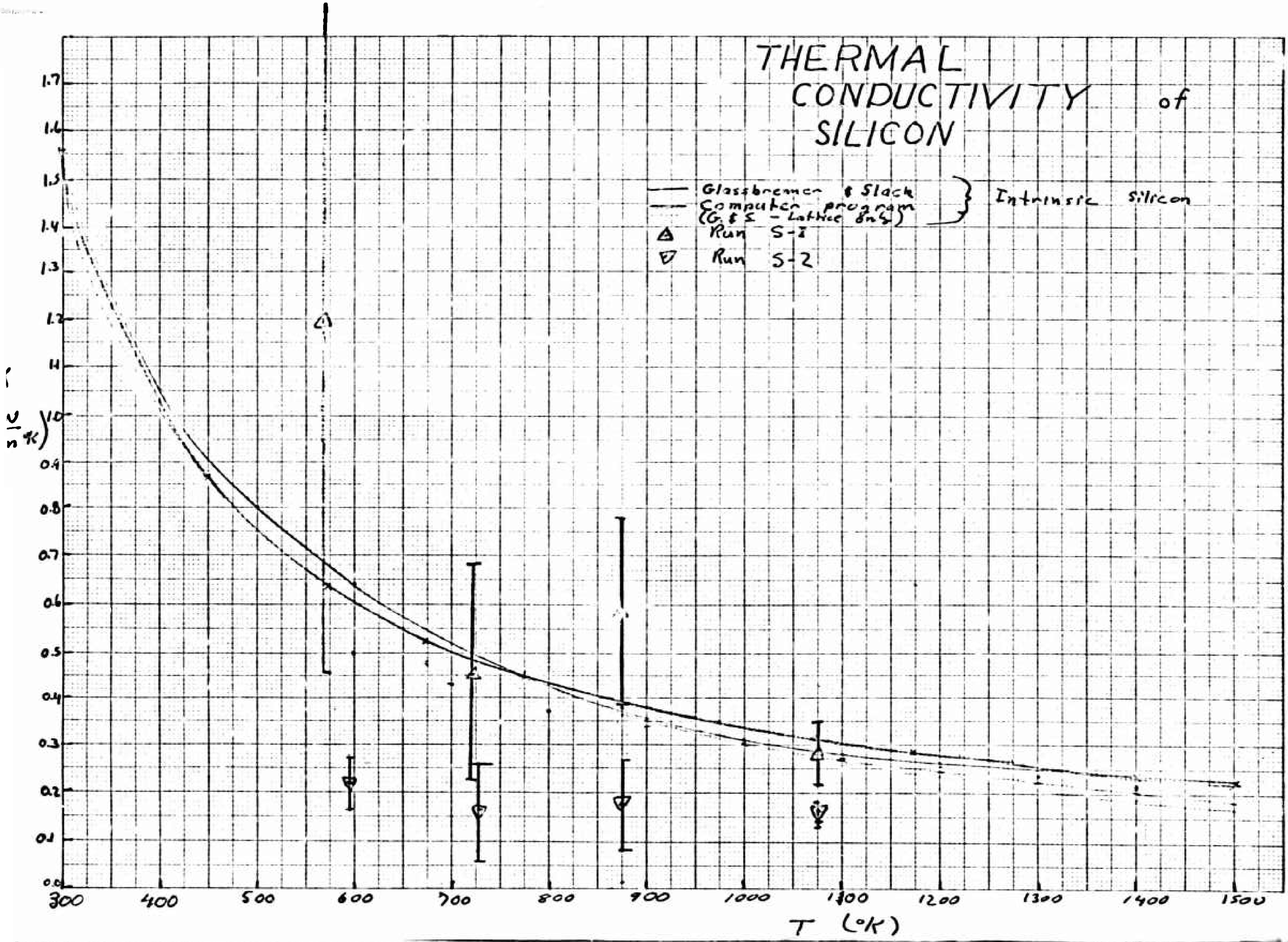
THERMAL CONDUCTIVITY of SILICON
Glassbrenner & Slack
Computer program (G. & S. - Lattice 8n's)
Intrinsic silicon
Run S-1
Run S-2
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
T (°K)

Figure 2 shows the results of Holyer's work along with those of other workers. We believe operation of the system is verified.

Work is now beginning on extension of the measurements to liquid helium temperatures. The material to be investigated will be InSb, pure and impure, in the range 4 - 300°K. We expect the first air shipment of liquid helium in October 1965. The graduate research assistant on this project is Emery J. Stephens.

5. MEDIUM-TEMPERATURE MEASUREMENTS: We have initiated a project to "go back and take another look" at our basic method of measurement in the range 300 - 700°K. Mr. Ronald R. Cox will investigate and evaluate each step of the work with regard to improving reliability and reducing errors. Some problems to investigate:

1. Radiation loss
2. Thermocouple separation uncertainties
3. Measurement sensitivities
4. Use of positive and negative temperature gradients.

The material to be studied will be silicon.

6. OTHER WORK: Work by men not receiving support from ONR but being done in our laboratory.

Measurements of thermal conductivity of boron:

T °K	K watt/cm deg
300	0.25 (ave.)
370	0.29
410	0.28
470	0.21
630	0.17

Slack's (Phys. Rev. 139, A507(1965)) room-temperature value (he measured T ≤ 300°) is 0.28 watt/cm deg.

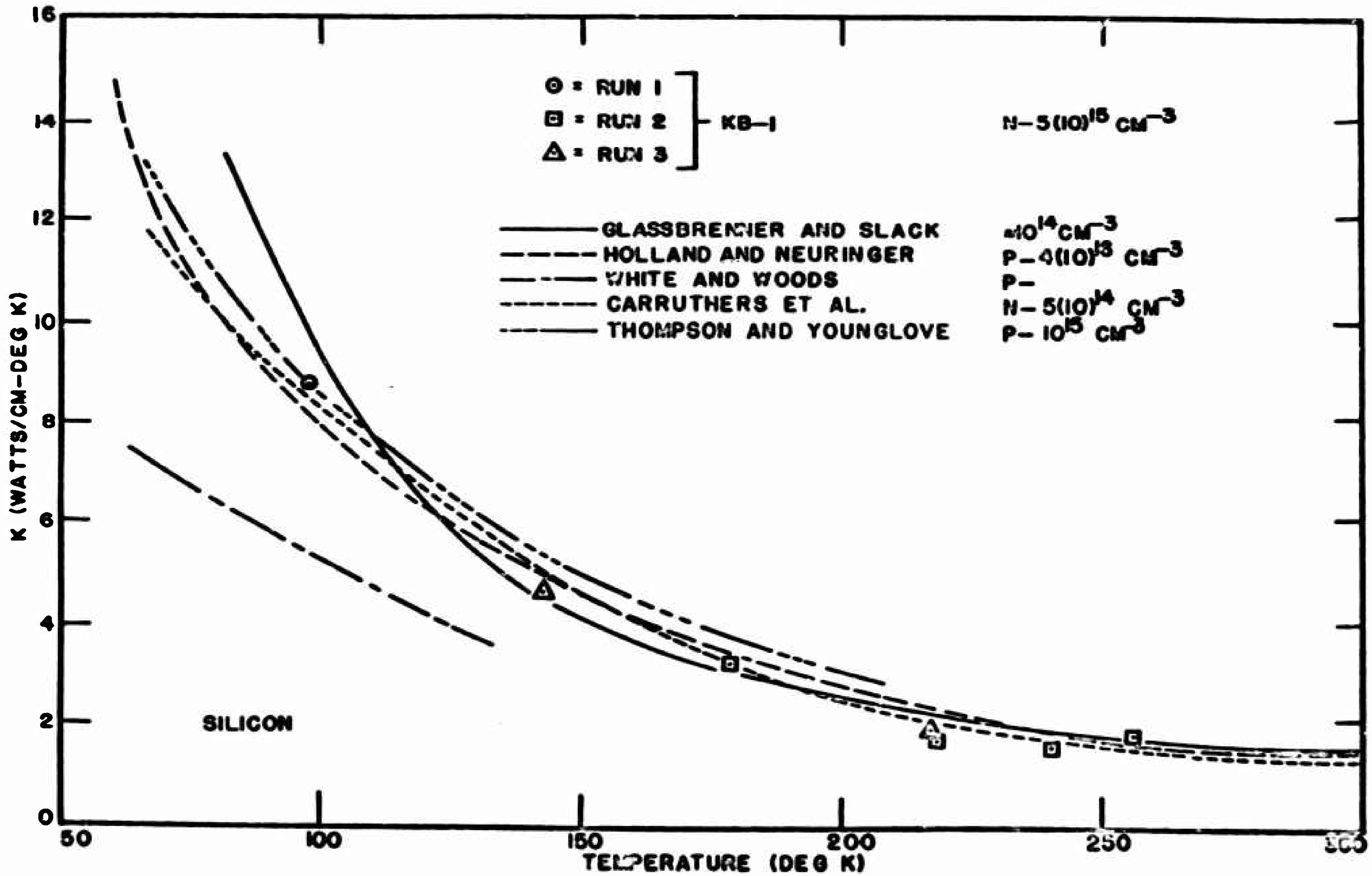

Fig. 2. Thermal conductivity of silicon. Shown also are results of other investigators.

f) <u>Personnel Changes</u>

as of 1 June 1965

D. Hill, undergraduate Research Assistant, leaves payroll (graduation)

R. Rollins becomes Undergraduate Research Assistant.

as of 1 September 1965

Leaving payroll:

Graduate Research Assistants

Ralph L. Benbow

Ronald J. Holyer

New on payroll:

Graduate Research Assistants

Ronald R. Cox

Emery J. Stephans

Date: 30 September 1965

Robert G Morris

Robert G. Morris, Principal Investigator

A System for Low-Temperature Measurements of Thermal Conductivity Measurements of Silicon from 77° to 300°K

by

Ronald J. Helyer

ABSTRACT

A system has been designed and constructed to measure thermal conductivity by the series comparative method in the temperature range 4° to 300°K. A sample temperature of 77°K was reached when the cylindrical sample chamber 3-1/4 inches in diameter and 8-3/4 inches long was evacuated to a pressure of $3X10^{-6}$ Torr and submerged in a bath of liquid nitrogen held in a 5-1/2 liter stainless-steel dewar. Temperatures as low as 4.2°K could be obtained if the sample chamber were submerged in liquid helium. Temperatures between that of the liquid bath and room temperature were obtained by electrical heating. A simple Wheatstone bridge circuit, one arm of which was a copper resistance thermometer made from 140 ohms of B and S No. 36 copper wire, served to regulate automatically the electrical heating so as to give a drift in sample temperature of less than 0.002 deg/min. Measurements were attempted from 77°K to 300°K on a sample of n-type single-crystal silicon with an impurity concentration of $5X10^{15}$ cm^{-3}. Armco iron was used as a standard. Temperatures were measured with copper vs constantan thermocouples. The thermal conductivity of the sample was found to range from 8.7 watt/cm-degK at 98°K to 1.8 watt/cm-degK at 255°K. These values agree with those of Carruthers et al. (3) within 7% and of Glassbrenner and Slack (5) within 10%. Comparison of results with results obtained by other investigators suggests the reliability and the accuracy of the apparatus and of the method at low temperatures.